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TECHNICAL REPORT SDC 279-3-6

FUNCTIONAL RELATIONSHIP OF TIME DENSITY TO THE DETECTION OF DISCRETE RADAR TARGET EVENTS

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PREFACE

The initial planning, experimental design, and laboratory work for this study were conducted by Drs. A. Lefford and R. E. Taubman; analytic and write-up phases were handled by Mr. H. W. Sinaiko.

Grateful acknowledgment is made to the following persons whose cooperation made this study possible: Lcdr. R. W. Weber, Lts. D. L. Whittemore, J. R. Zeitvogel, F. M. Guttenberger, M. Skees, and Lt(j.g.) G. F. Pean, experimental subjects; Mr. N. March, statistician; Miss Beryl Singleton, secretary; and Mr. David M. Goodman and Mr. Robert F. Avrutik, electronics engineers.

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1.0 SUMMARY

1.1 Purpose: The purpose of this laboratory study was twofold:

a. To explore the functional relations between time density and the probability that a radar operator would detect several different kinds of scope events.

b. To develop a "difficulty index" for these different scope events which could be used in controlling input stimuli for further experimental study on the Cadillac III Combat Information Center system. (Time density is defined as the number of discrete target events occurring per unit time--the time unit used being one minute.) The effects of time density were systematically explored over the range one to five discrete targets events per minute.

1.2 Data: Data were obtained in a laboratory experiment in which the subjects worked with the radar equipment designed for the Combat Information Center of the Navy P01W aircraft. The six subjects (experienced CIC officers) were asked to report continuously on the scope events presented to them. These verbal reports were electrically recorded while a photographic record of successive scope pictures was made. A total of ten experimental sessions was run in each of which three subjects participate, making a total of 30 individual runs.

1.3 Conclusions: The following tabulation contains an abbreviated statement of the results of this study

	Probability of Detection (within one minute)				
	Time Densities				
Different Events	1	2	3	4	5
New Targets	1.00	.97	.84	.50	.56
Fades	.83	.50	.37	.18	.15
Reappearances	-	1.00	.51	.28	.40
IFF	.85	.46	.40	.36	.38
Course Changes	.16	.06	.06	.06	.03

In terms of these data the two-fold purpose of the experiment was realized:

[redacted]

a. The functional relation between the probability of detecting discrete events and time density was demonstrated to be probability function. This function has the form

$$p = ae^{bx}$$

where x represents time density in other than a linear form. The implications of this relation are discussed in the body of this report.

b. In a gross sense, a hierarchy of kinds of discrete events has been established in terms of the difficulty for the radar operator to detect them. For instance, a new target is most easily detected while a course change is much more difficult to detect within the same time limit.

2.0 THE EXPERIMENTAL STUDY

2.1 Experimental Design

All data were collected in five days of laboratory time. Each of the six subjects was tested five times: two experimental runs per subject on two days, one run on a third. Each day in the laboratory was followed by one of rest.

Time density, the principal variable under investigation, was controlled as follows: A script was designed containing the precise time sequence for the introduction of stimuli. The total running time of twenty-five minutes was divided into four periods of four minutes and one final period of five minutes. One target event occurred during each minute of the first period (0 to 3 minutes), two target events occurred per minute during the next four minutes (4 to 7 minutes), and so on. Thus, as running time increased there was a corresponding increase in time density. Figure 1 shows a summary of the problem stimuli characteristics in their time relationships.

It is apparent that three variables were locked by the experimental design. That is, time density, target load, and running time varied concurrently: there were concomitant increases in both time density and number of targets on the scope during successive minutes of the run. This artifact necessarily limits any interpretation of results of the study in terms of time density as an independent variable. It is not possible to attribute variation in subjects' performance solely to differences in time density load, since length of time at the task

[redacted]

and target load were not held constant. However, it should be kept in mind that in operational situations--when a CIC system is actually confronted with air target detection--time density and number of targets are highly correlated. Rarely, if ever, would time density be low if target load were high; nor would the converse prevail. This experiment duplicated operational conditions where the three variables--running time, time density, and target load--will usually be very highly correlated. In later studies yet to be reported the independent effects of these factors will be shown.

2.2 Apparatus

The experiment was performed in a full-scale laboratory mockup of the PO-1W airplane. Each subject operated an IP-48 repeater console of the APA/56 remote radar indicator. Equipment was identical with that used in the airborne CIC Cadillac III system. Each console showed a 200 mile range (length of sweep) with a polar grid consisting of 30° angle marks and 10-mile range rings. Subjects adjusted the video gain to their own preferences.

2.3 Target Simulation

Radar targets were simulated by the aircraft target generator 15-AM-1* device. Each of the 15 air targets simulated for this study was controlled by an independent target generator unit. This permitted targets to be set in at predetermined initial positions and at courses and speeds independent of other targets.

* Target Simulator for Cadillac Evaluator: Device 15-AM-1; O.N.R., Special Devices Center, Report No. 42 (N8-2), November 14, 1949 (Confidential)

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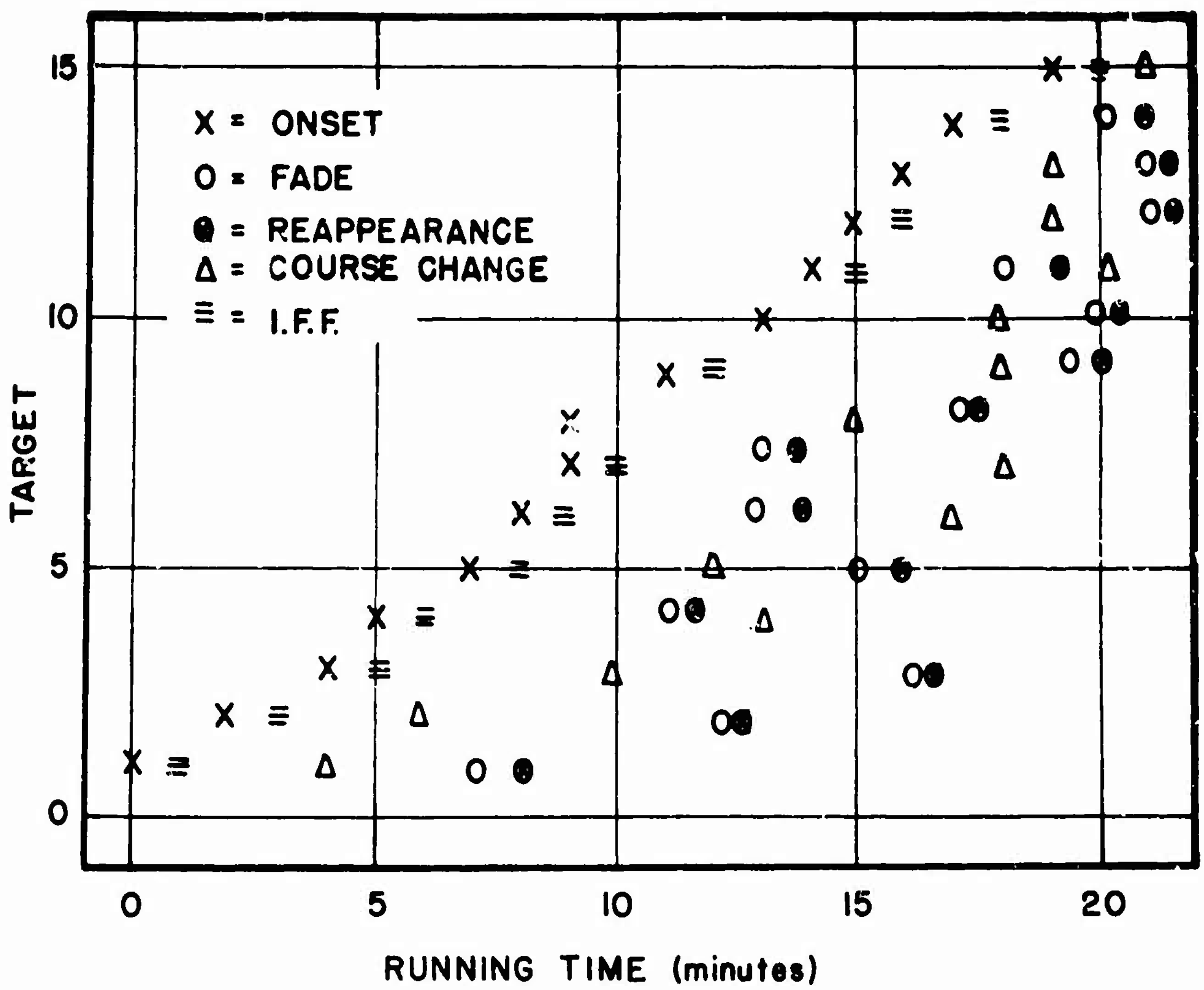

FIG. I EXPERIMENTIAL DESIGN: DISTRIBUTION OF TARGET EVENTS BY TIME AND TARGET.

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2.4 Instructions to Subjects

Subjects were told to expect radar targets on their scopes at random positions and at random times. Instructions were to make verbal reports immediately upon observing any of the following: new targets, target fades, reappearance of faded targets, IFF signals, or target course changes. Range, bearing, course, and speed of each target were to be reported as frequently as possible, with priority given to the detection of any of the events listed above.

Judgments of range, bearing, course, and speed were to be visually estimated, using only the 10 mile range rings and 30° angle marks appearing on the scope. Subjects were told to maintain target plots at their own most convenient rates.

2.5 Problem Input

Experience with an earlier study in this series of investigations (SDC 279-3-4) showed that problems of about one-half hour in length, and containing 15 air targets, would present sufficiently heavy loads to the subjects. Initial target positions were selected that would place targets toward the periphery of the scope and these positions were so arranged as to appear through the entire 360°. Target speeds ranged from 300 to 590 knots with faster targets being introduced later in the problem. (This was done so that targets appearing near the end of the run would produce sufficiently long tracks to permit speed and course estimates.) Courses varied through 360 degrees but targets generally headed toward the center of the scope. Eight of the 15 targets showed an IFF or "friendly" signal.

[redacted]

Table 1 summarizes all target characteristics including time sequences. Figure 2 shows target tracks as they appeared at the end of each run.

The experimental design included five replications of the same stimulus. The likelihood of subjects' learning the stimulus pattern was reduced by rotating the problem 90° in successive presentations. Thus, each subject perceived a different stimulus on each successive day although actually these stimuli were spatially and temporally identical.

2.6 Subjects

Experimental subjects were five Naval officers with ranks of Lcdr., Lt., and Lt(jg). All subjects had participated in earlier studies utilizing the Cadillac III equipment, and each of the officers had been in shipboard or airborne CIC work prior to his assignment to this research project.

2.7 Recording of Data

Subjects' reports were recorded simultaneously on wire. Photographs of the PPI scope face were taken automatically once during each sweep, or every ten seconds. It was then possible, in preparing the data for analysis, to transcribe all reports (positions, courses, speeds, fades, reappearances, IFF signals, and course changes) with an accompanying time base. By projecting the film records the experimenters could determine target performance, as it actually appeared to the subjects, with some high measure of precision.

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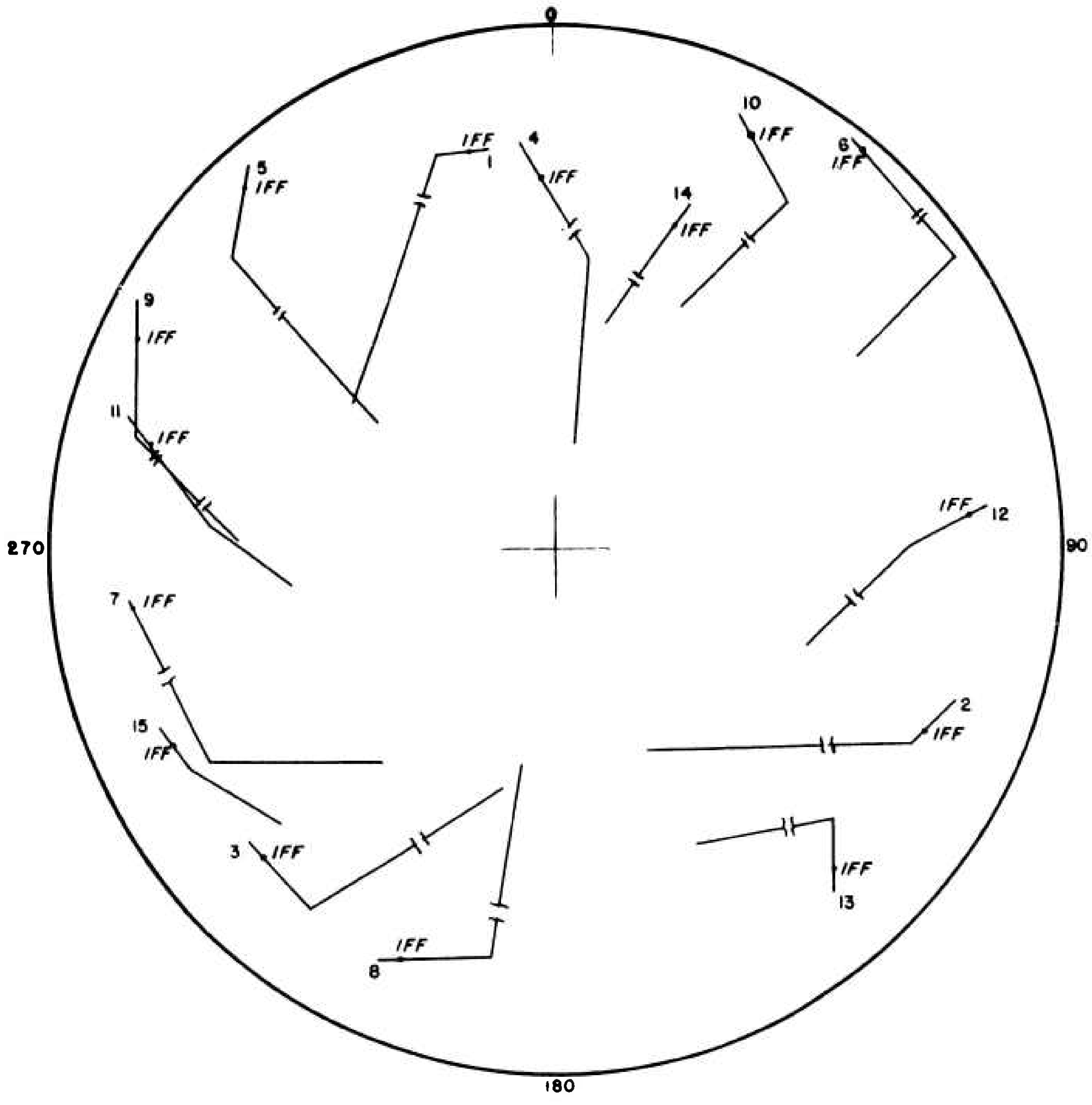

FIGURE 2

SCHEMATIC REPRESENTATION OF THE PROBLEM

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Table 1

Target Characteristics

Target Number	Initial Position	Course Initial	Course Final	Speed	Time Onset	Time Fade	Time Reappearance	Time IFF	Time Course Change
1	N45 W45	270°	200°	300	00:00	07:00	08:00	01:00	04:00
2	S60 E155	225°	270°	330	02:00	12:00	12:30	03:00	06:00
3	S110 W120	135°	060°	350	04:00	16:00	16:30	05:00	10:00
4	N155 W10	150°	180°	370	05:00	11:00	11:30	06:00	13:00
5	N145 W120	190°	140°	390	07:00	15:00	16:00	08:00	12:00
6	N155 E95	135°	225°	400	08:00	13:00	14:00	09:00	17:00
7	S25 W70	150°	090°	430	09:00	13:00	14:00	10:00	18:00
8	S155 W70	090°	010°	450	09:00	17:00	17:30	10:00	15:00
9	N95 W165	180°	135°	470	11:00	19:00	20:00	12:00	18:00
10	N165 E70	150°	225°	490	13:00	20:00	20:30	14:00	18:00
11	N45 W155	140°	130°	500	14:00	18:00	19:00	15:00	20:00
12	N10 E170	250°	230°	530	15:00	21:00	21:30	16:00	19:00
13	S130 E110	000°	260°	550	16:00	21:00	21:30	17:00	19:00
14	N135 E50	210°	240°	570	17:00	20:00	21:00	18:00	
15	S70 W155	140°	120°	590	19:00			20:00	21:00

[redacted]

3.0 RESULTS

Data treatment was determined in this study, as in all exploratory work, by the nature of the data obtained. The instrumentation requirements and the necessity for experimental control of certain variables is not apparent when study in a new area is begun. Refinement in analytical treatment must be that which the data warrants.

The results contained in this section are those, out of a number initially considered, which meet the experimenters' criterion of scientific adequacy. Discussion of the implications for each type of radar event detection (new targets, fades, and reappearances, IFF signals and course changes) follows in the next section.

3.1 Detection of New Targets

Table 2 and Figure 3 summarize the relation between time density load and the probability of detecting new targets. With this radar equipment the scan rotated six times per minute. Data have been related directly to scan time: probabilities for detecting new targets under varying conditions of time density are expressed in time increments of radar scans. (One scan equals .16 minutes). Sixteen experimental runs, for which adequate time data were available, are included.

3.2 Detection of Fades and Reappearances of Targets

In analyzing the data on target fades and reappearances it was not advisable to consider detection time as such. Rather, the probability of detecting an event at all, within the specified time limit of one minute, was computed. This was done

Table 2

Probability of Detecting New Targets as a Function of Time Density

Detection Time (Minutes)	Scope Scans	Time Density				
		1	2	3	4	5
.16	1	.86	.44	.16	.19	.10
.33	2	1.00	.74	.40	.25	.23
.50	3	1.00	.94	.54	.33	.28
.66	4	1.00	.94	.72	.47	.41
.83	5	1.00	.97	.80	.47	.49
1.00	6	1.00	.97	.84	.50	.56
1.16	7	1.00	.97	.88	.58	.64
1.33	8	1.00	.97	.94	.64	.72

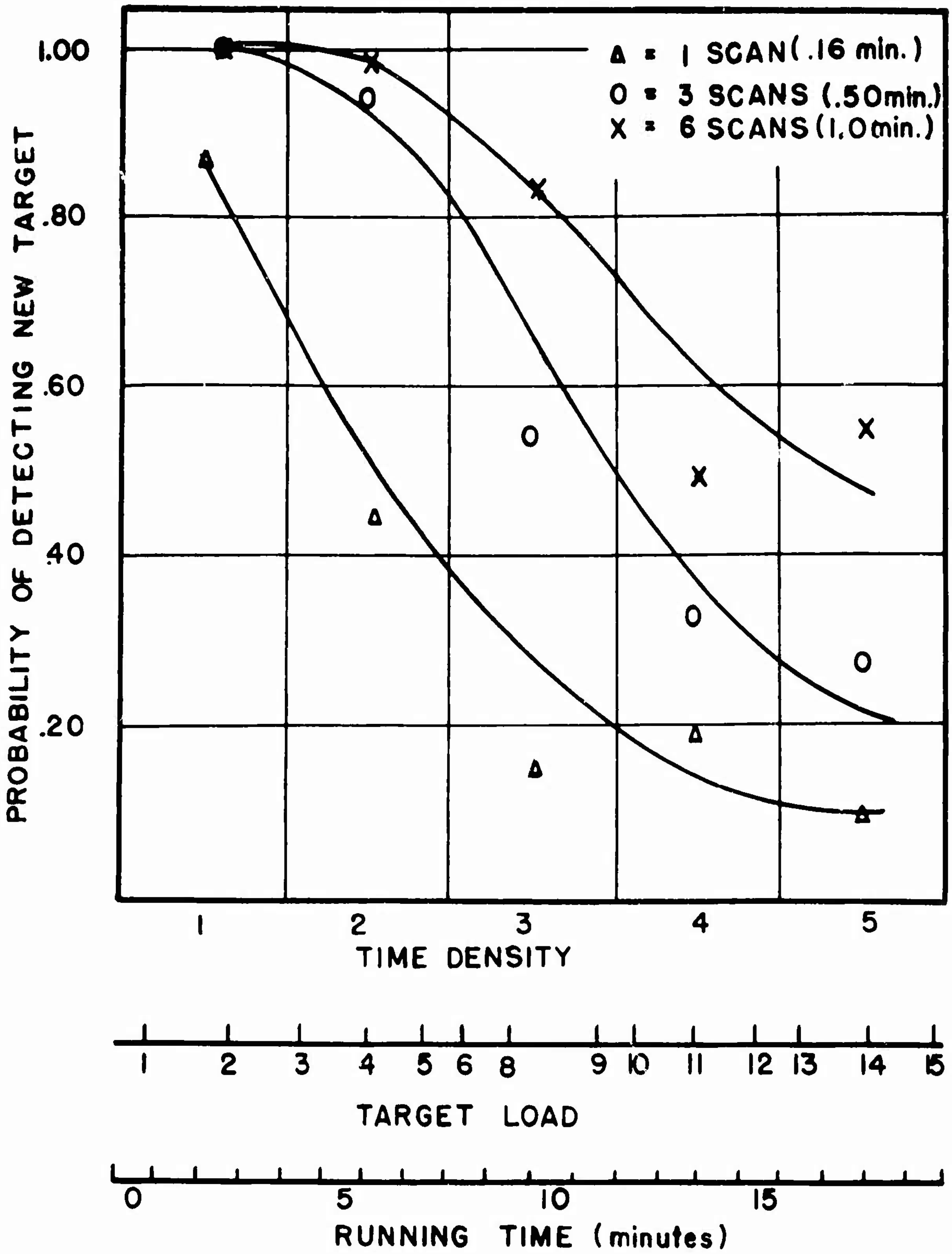

FIG. 3 PROBABILITY CURVES FOR DETECTION OF NEW TARGETS.

because every time a target faded, it remained faded for more than one minute. In other words, if a faded target was not detected and reported as such within at least one minute, that target would reappear on the scope. Table 3 summarizes the findings on the detection of target fades and reappearances. Data from 30 experimental runs, and including all six subjects, are included. In evaluating the subjects' records correct detections were counted if reports of fades or reappearances occurred with one minute of "script" and time of event. For example, when Target 1 faded at minute 7, all detections and reports made between minutes 7 and 8 were counted as correct. Similarly, a report of the reappearance of a target subsequent to its fading, was tallied as correct if it occurred with one minute of the actual time of reappearance.

Figure 4 shows the relation between fade and reappearance detections and the principal dependent variable under investigation--time density.

Table 3

Probability of Detecting Fades
and Reappearances as a Function of Time Density

Time Density	Probability of Detection within 1 minute	
	Fades	Reappearances
1	.83	
2	.50	1.00
3	.37	.51
4	.18	.28
5	.15	.40

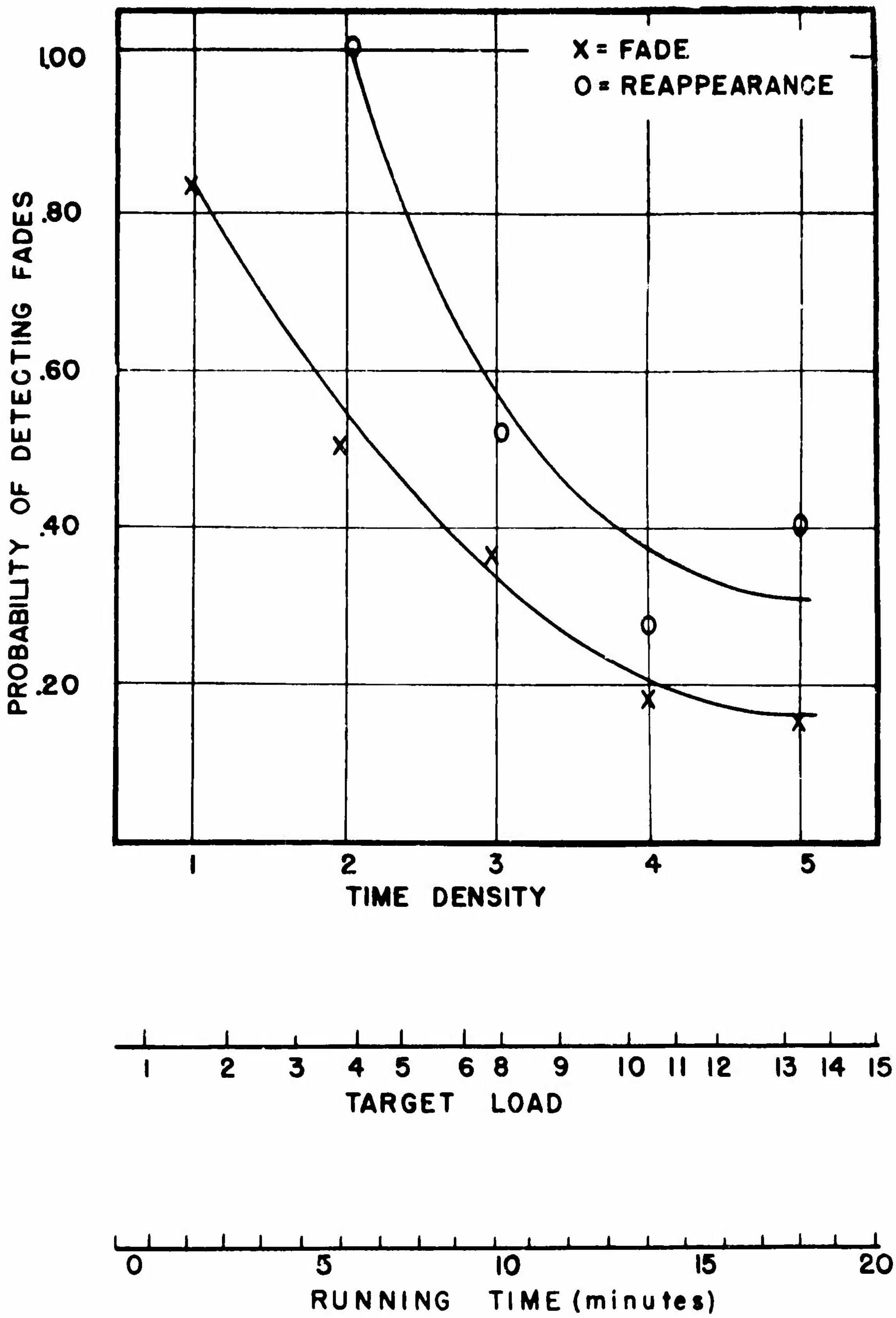

FIG. 4 PROBABILITY CURVE FOR DETECTION OF FADED AND REAPPEARED TARGETS.

3.3 Detection of IFF Signals

Eight of the 15 targets used in the study were designated as friendly in the experimental design. Whether a target showed IFF or not, a discrete event was considered to have occurred in the minute following the target's initial appearance. Non-appearance of the IFF signal was in itself a target event since it identified the target as enemy. It was not possible, however, to score the subjects' verbal reports except for the friendly response. Table 4 summarizes the probabilities for correctly identifying an IFF signal within one minute of its appearance under varying conditions of time density.

Table 4

Probability of Identifying Friendly Targets (IFF) as a Function of Time Density

Time Density	Probability of Reporting IFF Within 1 Minute
1	.85
2	.46
3	.40
4	.36
5	.38

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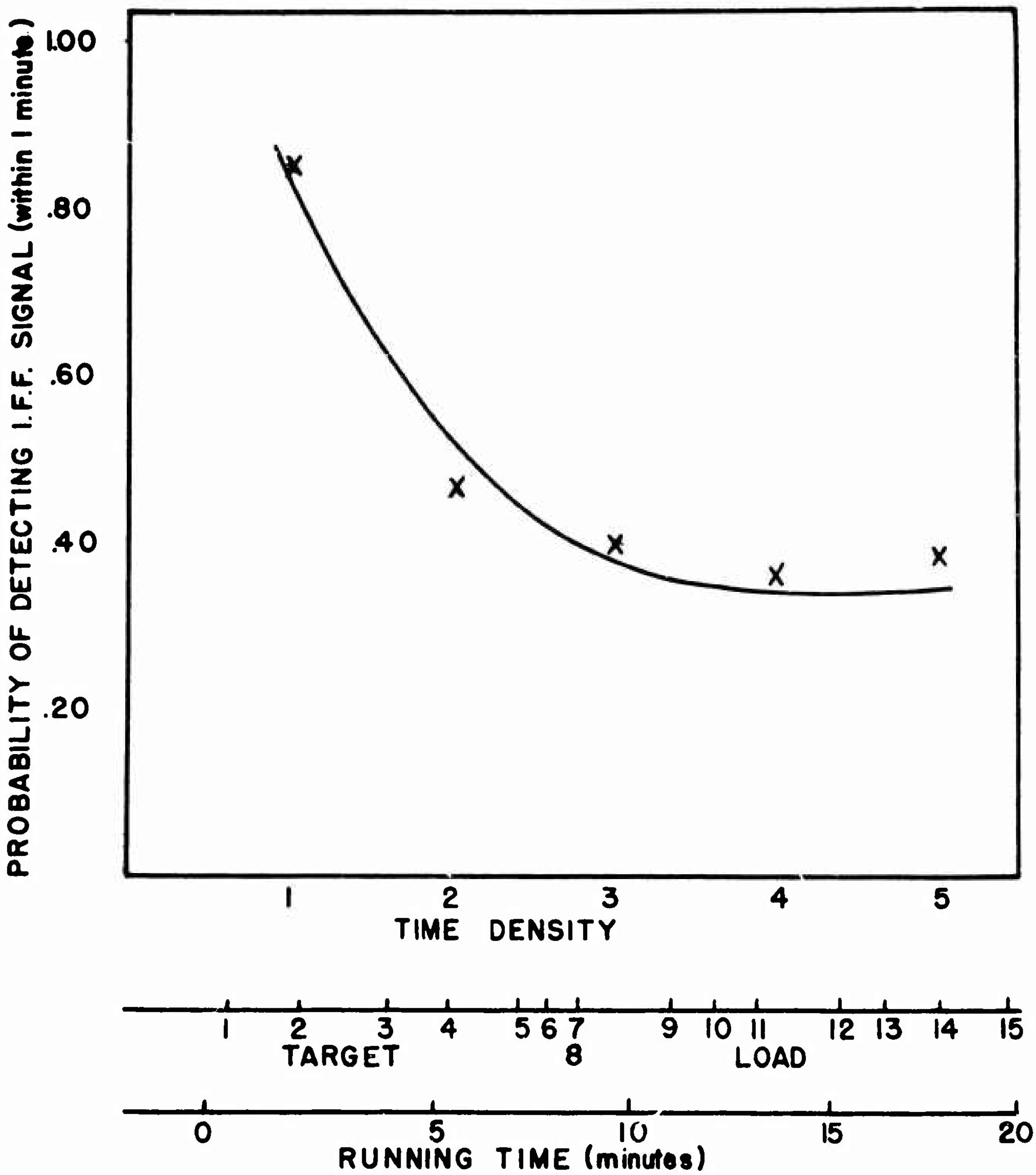

FIG. 5 PROBABILITY CURVE FOR DETECTION OF I.F.F. SIGNAL.

[redacted]

Figure 5 shows the probability for identification of friendly radar targets plotted against time density load.

3.4 Detection of Course Changes

With one exception, each of the targets in the problem made one course change. The absolute amount of each course change varied from target to target but was held constant from one experimental run to another. Table 5 summarizes the probabilities for detecting course changes within time limits of 1 minute, 2 minutes, and 3 minutes. Figure 6 shows the three detection probability curves plotted against time density.

Inspection of the data revealed that the magnitude of the course change of a target affected the probability of detection of that course change. There were six course changes that took place during the time that time density was 4. In this instance, $p = .25$ (degrees of course change) would roughly predict performance. It is hypothesized that for other values of time density, the linear relation would prevail with a different slope for each time density--all lines passing through the origin. The number of course changes within each other value of time density was not sufficient to test this possibility.

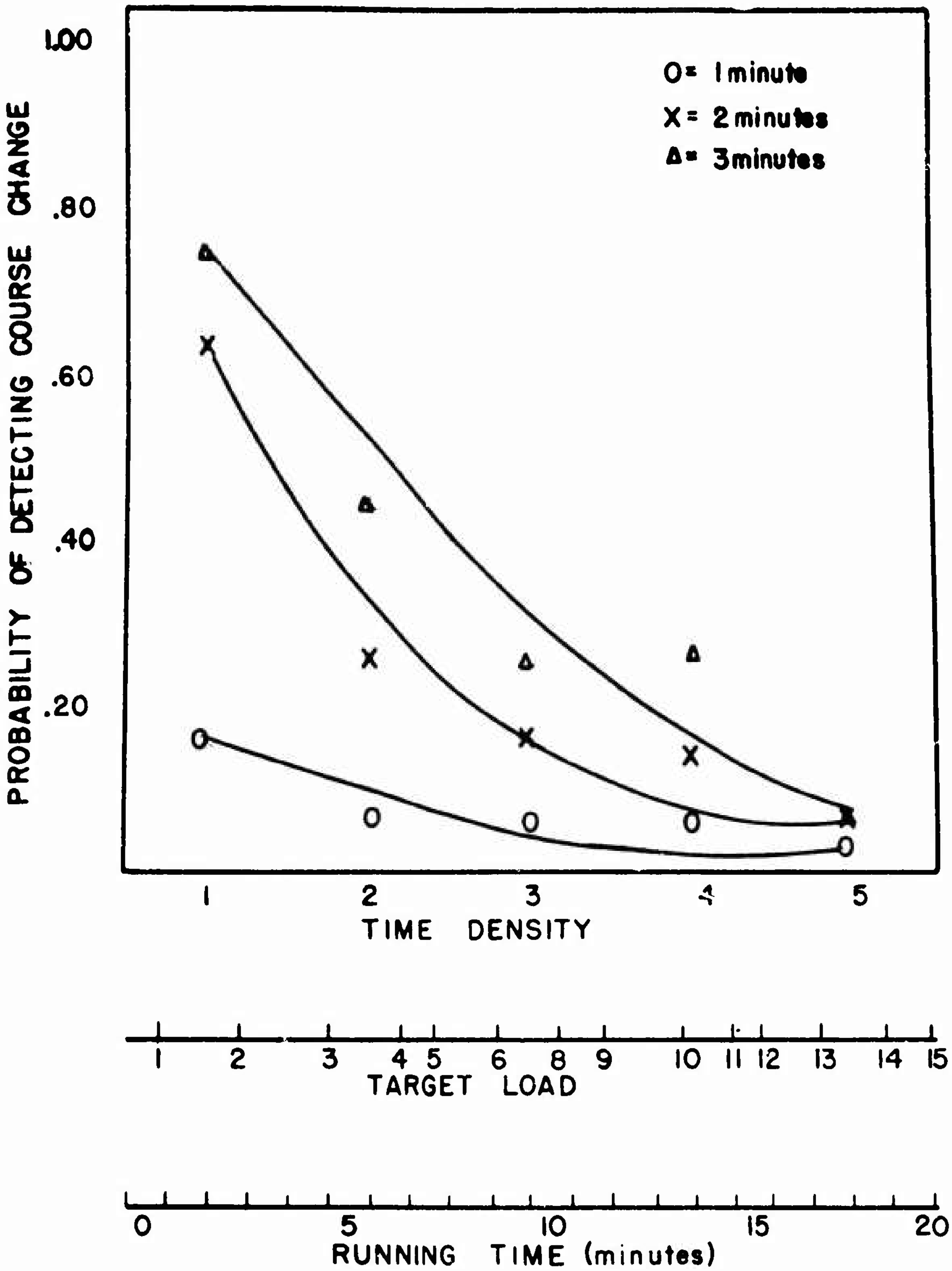

FIG. 6 PROBABILITY CURVE FOR DETECTION OF COURSE CHANGE.

Table 5

Detection of Target Course Changes as a Function of Time Density

Time Density	Probability of Detection		
	Within 1 Min.	Within 2 Min.	Within 3 Min.
1	.16	.63	.75
2	.06	.25	.44
3	.06	.16	.25
4	.06	.14	.26
5	.03	.06	.06

4.0 DISCUSSION

The program of systems research, of which the present investigation is a preliminary component, is devoted to a study of an area characterized by very little previous experimental work. The way of approaching this problem, and others that preceded it, may be described as consisting of three steps. First, the investigators made extensive observations of the individual radar operator's task. These subjective observations indicated that quickness of response, accuracy, and rate of production of console operators was affected by space and time density and the target load. Second, and following these impressions, a subsystem study* was set up which varied space density (target load) in order to find a functional relation between this variable and certain aspects of radar operator performance. Finally, when the relation between target load and target detection time was defined, the present study was undertaken in order to explore the time density variable.

The general procedure for analyzing the results of this study was essentially an inductive one. Conventional analysis of data produced several points of inconsistency; e.g., there were very few detections of an I.F.F. signal for two particular targets in spite of a relatively low time density during these respective events. It became necessary, then, to locate the causes for such deviant subject performance by studying the

*See Technical Report SDC 279-3-4 "Preliminary Studies of Detection Time and Other Factors Involved in AEW Performance"

specific instances of inconsistency. The investigators turned to other data--script, spatial distribution, etc.--in order to determine whether factors other than load and time density could be held responsible for the observed inconsistencies. In the sections to follow, which discuss the implications of this study's findings, it will be apparent that factors other than those controlled in the design did contribute to the function; in some cases, therefore, it has been possible to find the effects of other factors on performance by inductive exploration of the data.

4.1 Detection of New Targets

An obviously important function of the CIC is the rapid detection of new targets as they come within radar range of the system. An earlier study* established the fact that detection time of new targets was affected by space density. That is, as the number of targets in a problem increased, detection of succession of new targets took more and more time. It was possible to predict (when time density was below .5) that it would take a radar operator 0.1 minute to detect a new target appearing on a previously blank scope; with 14 targets already on the scope, the average time taken to detect an additonal new target would be 1.3 minutes. These facts about new target detection time were established in a relatively non-complex experimental situation: subjects were merely required to report appearances, courses, speeds, and bearings of targets

*Technical Report SDC 279-3-4 Preliminary Studies in Detection Time and Other Factors in AEW Performance

on their scopes. The present experiment, it will be recalled, introduced several new types of target phenomena: fading, IFF, and course change.

It took longer to detect new targets as time density increased. The probability that an operator would observe and report a new target ~~within~~ one scan, or .16 minutes, with no other events occurring on his scope during that minute, was .86. With a single other event occurring, the operator's detection time of a new target increased. Or, in terms of detection within one scan (.16 minutes), the probability became .44. With as many as three other events (time density of 4) taking place when a new target appeared, the probability of that target detection within 1 scan dropped to .18.

For example, when target 14 appeared on the scope the following events occurred during that minute: target 13 showed an IFF signal, target 8 faded and reappeared, and target 6 altered its course 90 degrees. It was the subjects' task to report each of these events as soon as possible. The probability of detecting the initial appearance of target 14 within 1 scan was only .10.

In Figure 7, the results of this study (concerned with time density) are compared with those of SDC Technical Report 279-3-4 (concerned with space density). The time density maintained throughout the previous study was .75; the time density of this study varied from 1 through 5. It will be noted that the increased time density of events for this study reduced the probability of detecting new targets within one

minute. Time density can, therefore, be identified as a factor of the stimulus influencing operator performance. Space density (or target load) may be the more influential factor; that is, a high target load (over 10) may be so difficult that time density does not appreciably affect operator performance.

4.2 Detection of Fading and Reappearing Targets

A frequent phenomenon on a radar scope is the fading and subsequent reappearance of targets. It is apparent that the disappearance of a target makes the tracking task more complex. The operator must accurately determine the time and location of the last appearance of the target and maintain a tentative track which help identify that target when it reappears. In the present experiment each target, with one exception was faded and brought back in once during the problem runs. Seven targets were faded for duration of one minute, and the remaining seven were faded for one-half minute each. See Figure 1 for the time sequence and spatial distribution of these fade events.

Results indicated that there was a decrement in the probability of detecting faded targets with an increase in time density, although the detection of a fade at all was considerably less likely than that of accurately detecting and reporting a new target. The preceding section on new target detections indicated that in no instance did a subject fail completely to report a new target on the scope, regardless of high time density saturation. However, in no case was any target's fading reported in all subject runs, even when time density was 1 (no other events during that minute). The curvilinear relationship

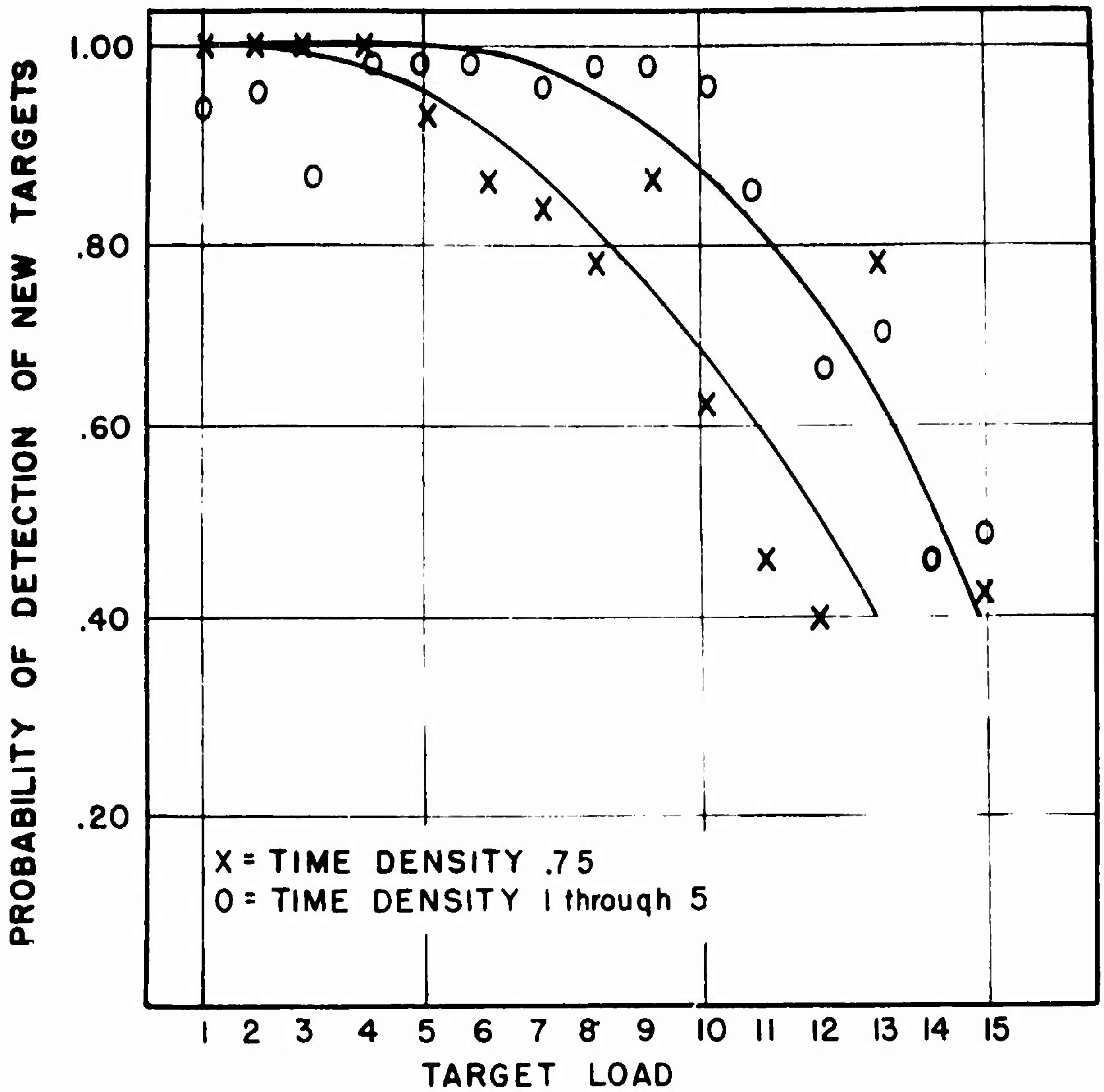

FIG. 7 PROBABILITY CURVES FOR NEW TARGET DETECTIONS WITH CONSTANT AND VARYING TIME DENSITIES.

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between correct detection of faded targets and time density (see Figure 4) indicated that the greatest decrement in this performance occurred between time densities of 1 and 2, and 2 and 3; there was considerably less decrement as time density increased beyond 3. At this latter point it appeared that the curve had reached an asymptote, with the likelihood of detecting a fade during time densities of 4 or 5 being very low and approximately equivalent. For example, the most accurately detected fade was reported at a rate of 83 times in 100. This particular fade occurred with no other concurrent events. With a single additional target event, time density of 2, correct fade detections dropped to .50 and with three other target events fading was observed fewer than 1 in 5 times, ($p = .18$). However, with four other events, time density of 5, the probability of detecting a faded target did not drop as markedly ($p = .15$) indicating a stable or leveling off point in the curve.

The detection of reappearing targets, that is, targets which had been previously reported as faded, was considerably better than fade detection. (To be counted as a correct detection, only close reappearances which were detected for targets that had been reported faded were tallied; furthermore, a reappearing target had to be reported within one minute after true reappearance time). The probability curve for reappearance detections (see Figure 4) approached in height and shape that for the detection of new targets. In other words, the two tasks--detecting new targets and detecting reappearing faded targets--seemed to be very similarly handled by the subjects.

[redacted]

Reappearance detections were functionally related to time density load, with the greatest decrement occurring between time densities 2 and 3. Beyond the latter point (for time densities 3, 4, and 5) there did not appear to be a sizeable differential, although operator detections did become somewhat less probable as time density loads increased.

4.3 Detections of IFF Signal

Friendly targets, which were indicated on the scope by an IFF signal, were detected by the subjects with probabilities ranging from .85 to .22. (Least to greatest degrees of time density.)

A curvalinear trend appeared when IFF detections were plotted against time density, although in this case there were inconsistencies in the data. The greatest decrement in detection of the friendly signal occurred between time densities of 1 and 2. Following the latter point the curve leveled off with practically no decrement in this kind of detection occurring regardless of whether time densities were 2, 3, or 4.

Targets 7 and 8 were very rarely identified friendly, although time density at the time of their respective IFF signals was relatively low. A tentative reason for this deviation is the fact that, due to the experimental design, these two targets gave simultaneous IFF signals. Such an occurrence might have been confusing, and consequently delaying, to the subjects. Thus, the probability of accurate identification of a friendly target would have necessarily been lowered.

4.4 Detection of Course Changes

The detection of a change in course of a target cannot be read directly from the scope; it can be noted only in terms of past history, of the target's movement as represented by the plotted track. It is obviously important for the operator to note quickly any change in a bogey's tactics. A bogey on a crossing course would become a potential danger if it turned towards the protected point. Even a slight change in the course of an enemy may mean that an intercept will not be made.

As indicated in the Results Section, the data indicates that an operator more readily detects an 80 degree course change than one of 10 degrees. The data is not extensive enough to describe this relation more explicitly.

The prbability of detecting a course change within one minute is much lower than that for detecting other target events. In Figure 6, the probability curves for detection within two and three minutes are also plotted. Those latter curves show considerable decrement with increase in time density although that decrement is not apparent in the probability curve for one minute.

5.0 CONCLUSIONS

As the result of this second exploratory study of radar operator performance, it can be concluded that these two aspects of the radar stimulus affect operator performance: space density (grossly measured as the number of targets on the scope) and time density (the number of discrete events per unit time). This study has been devoted to consideration of the second of these variables. The results can be summarized under two headings: 1) the nature of the functional relation between probability of detecting new target events and time density, and 2) the relative difficulty of detecting different kinds of target events.

These conclusions will be helpful not only in more effectively controlling the experimental stimuli in the study of the airborne CIC but also have implications for other work as well. It should be emphasized that this experiment was exploratory and thus expresses certain limitations in experimental control and in instrumentation; the results indicate the general nature of the functions without providing the precise parameters.

5.1 The Relation Between Time Density and Probability of Detection

The results of this study yield a family of curves which are of the form, $y = ae^{bx}$, where x is the time density variable in a form that does not seem to be linear. Further definition of the nature of the scale for time density does not seem to be warranted on the basis of these data. More extensive data should be gathered for this purpose where the time

density variables are not experimentally dependent; moreover, whether all types of discrete events can be added to obtain a meaningful time density value needs to be resolved by further data.

Figure 8 shows this family of curves of probability of detecting different kinds of target events within one minute. There is a sharp decrement in performance in the detection of new targets between time densities 2, 3, and 4 with an indicated asymptotic relation for lower and higher values. The main decrement in the detection of reappearing targets occurs in the same area as with new targets. The detection of both fades and IFF signals fall off rapidly between time densities of 1 and 2; there continues to be a decrement in detection of fades to time density of 4 while the probability of detecting IFF signals levels off over the 2, 3, 4, and 5 range. The probability of detecting course changes within one minute is uniformly low.

The implications of these data point to division of labor in maintaining surveillance on the radar area if a high probability of detecting these events within one minute is desired. The necessity for performing these detections reliably within this short space of time can be determined, of course, only by an examination of the operational requirements demanded of a Combat Information Center system.

5.2 <u>Relative Difficulty of Detecting Different Kinds of Target Events</u>

Figure 8 shows that new targets are most readily de-

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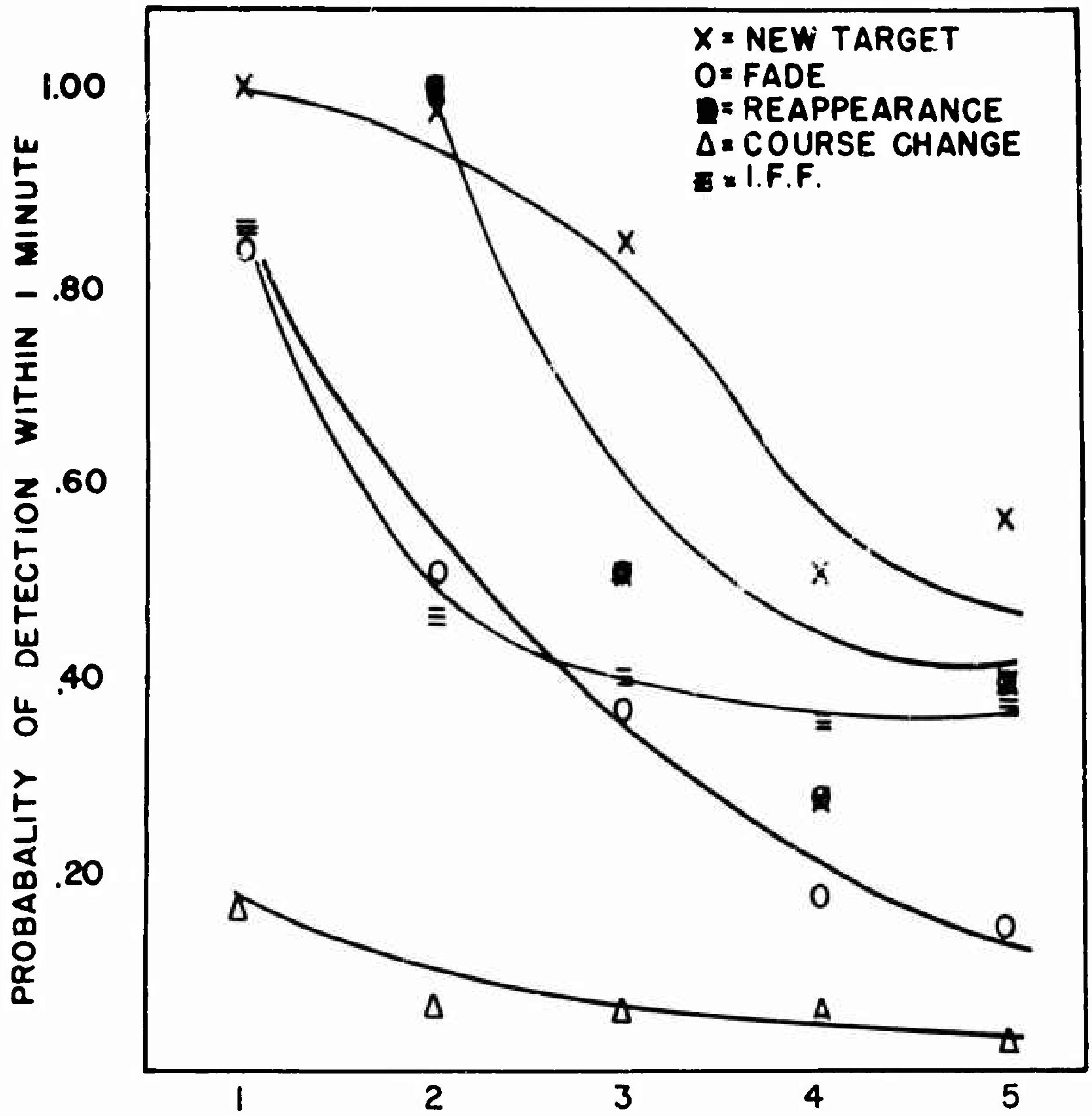

FIGURE 8. PROBABILITY CURVES FOR DETECTION OF FIVE KINDS OF TARGET EVENTS.

[redacted]

tected; reappearing targets and fades follow; the detecting of IFF signals at higher time densities is about equal in difficulty to detecting reappearing targets. Course changes are much more difficult to detect within the same period of time.

It would appear that the radar operator can more readily notice an event which occurs in the blank areas of the scope; That is, in those areas where he has no targets or tracks. Whether new targets would continue to be detected more readily than other target events in the presence of radar noise remains to be demonstrated. This result may depend on a sharp contrast between figure and ground which will not obtain under actual operational conditions. Course changes take longer to detect because they must be made on the basis of a track which accumulates and is a function, no doubt, of the frequency with which the operator can plot any target.